Chapter Seventy-seven 4

77-1.0 GENERAL....................4
77-1.01 MUTCD Context....................4
77-1.02 References....................4
77-1.03 Official Action....................5
77-1.04 Project/Plan Development....................5
77-1.05 Definitions....................5

77-2.0 PRELIMINARY DESIGN ACTIVITIES....................7
77-2.02 Signal Warrants....................8
77-2.03 Warrant Analysis....................9
77-2.04 Responsibilities....................10

77-3.0 FLASHERS/FLASHING BEACONS....................11
77-3.01 Guidelines for Hazard Identification Beacons....................11
77-3.02 Speed Limit Sign Beacon....................11
77-3.03 Intersection Control Beacon....................11
77-3.04 Stop Sign Beacon....................12
77-3.05 General Beacon Design....................13

77-4.0 TRAFFIC SIGNAL EQUIPMENT....................14
77-4.01 Traffic Controllers....................14
77-4.01(01) Pretimed Controller....................14
77-4.01(02) Semi-Actuated Controller....................15
77-4.01(03) Fully Actuated Controller....................17
77-4.01(04) Actuated Controller with Density Feature....................18
77-4.01(05) Pedestrian Feature....................19
77-4.01(06) Controllers with Specialty Features....................20
77-4.01(07) Controller Design Concepts....................20
77-4.01(08) Associated Controller Equipment....................21
77-4.01(09) Conflict Monitor....................21
77-4.01(10) Controller Cabinets....................21
77-4.01(11) Preemption....................22
77-4.02 Detectors....................24
77-4.02(01) Operation....................24
77-4.02(03) Other Detector Types....................26
77-4.02(04) Pedestrian Detectors....................27
77-4.02(05) Bicycle Detectors....................28
77-4.03 Signal Mounting....................28
77-4.04 Signal Display....................29

77-5.0 TRAFFIC SIGNAL DESIGN....................31

77-5.01 Design Criteria....................31
77-5.01(01) Signal Displays....................31
77-5.01(02) Visibility Requirements....................32
77-5.02 Placement of Signal Equipment....................33
77-5.03 Pedestrian Signals....................35
77-5.04 Pavement Marking and Signing....................35
77-5.05 Electrical System....................35
77-5.06 Phasing....................37
77-5.06(01) Phasing Types....................37
77-5.06(02) Left-Turn Phases....................39
77-5.07 Pretimed Traffic Signal Timing....................40
77-5.07(01) Guidelines for Signal Timing....................40
77-5.07(02) Cycle Determinations....................42
77-5.08 Actuated Controller Settings....................44
77-5.08(01) Basic-Actuated Controllers....................45
77-5.08(02) Advanced-Design Actuated Controllers....................47
77-5.08(03) Actuated Controllers with Large Detection Areas....................48
77-5.09 Computer Software....................50

77-6.0 SIGNAL SYSTEM DESIGN....................52
77-6.01 System-Timing Parameters....................52
77-6.02 System Types....................53
77-6.02(01) Interconnected Time-of-Day System....................53
77-6.02(02) Time-Base-Coordinated Time-of-Day System....................53
77-6.02(03) Traffic-Responsive Arterial Systems....................54
77-6.02(04) Distributed-Master (Closed-Loop) Systems....................54
77-6.02(05) Central Computer Systems (Interval-Command Systems)....................55
77-6.02(06) Central Database-Driven Control Systems....................55
77-6.03 Communications Techniques....................56

List of Figures

Figure	**Title**
74-4A	Nema & Model 170 Controller
77-4B	Sequence of Phases
77-4C	Post-Mounted Signals
77-4D	Cable-Span Mounted Signals
77-4E	Cantilever-Mounted Signals
77-4F	Combination Signal-Luminaire Pole
77-4G	Cable-Span Mounted Signals (Bridle Configuration)
77-5A	Signal Placement (Offsetting Intersections)
77-5B	Signal Placement (Urban, Left-Turn Lane)

77-5C	Signal Placement (Urban, No Left-Turn Lane)
77-5D	Signal Placement (Permissible Left Turn)
77-5E	Signal Placement (Protected Left Turn)
77-5F	Signal Placement (Protected/Permissible Left Turn)
77-5G	Signal Placement (Multi-Lane Approach, Left-Turn Lane)
77-5H	Signal Placement (Multi-Lane Approach, Right/Left-Turn Lanes)
77-5 I	Minimum Visibility Distances
77-5J	Vision Cone
77-5K	Two-Phase Operation
77-5L	Three-Phase Operation (Separate Split Phases for Major Street)
77-5M	Three-Phase Operation (Separate Left-Turn Phase on Major Street)
77-5N	Three-Phase Operation (Exclusive Pedestrian Phase)
77-5 O	T Intersections
77-5P	Eight-Phase Operation (Dual Ring)
77-5Q	Comparison of Left-Turn Phase Alternatives
77-5R	Dilemma Zone
77-5S	Detection Setback Distances (m)

Chapter Seventy-seven

TRAFFIC SIGNALS

77-1.0 GENERAL

The design of traffic signals is one of the most dynamic fields of traffic engineering. Although this chapter will address several traffic signal design issues, it is impractical to present a complete traffic signal design guide. For detailed design information, the reader should review the latest editions of the references in Section 77-1.02. The intent of this chapter is to provide the user with an overview of the traffic signal design issues and to present INDOT's applicable positions, policies and procedures.

77-1.01 MUTCD Context

Throughout the *Manual on Uniform Traffic Control Devices (MUTCD)*, the words "shall," "should," and "may" are used to describe the appropriate application for various traffic control devices. Section 75-1.0 presents the Department's position on these qualifying words.

77-1.02 References

For additional information on traffic signal design, the designer is referred to the publications as follows:

1. *Manual on Uniform Traffic Control Devices*, FHWA;
2. *Standard Drawings*, INDOT;
3. *Standard Specifications*, INDOT;
4 *Highway Capacity Manual*, Transportation Research Board (TRB);
5. *Traffic Control Devices Handbook*, FHWA;
6. *Manual of Traffic Signal Design*, Institute of Transportation Engineers (ITE);
7. *Traffic Engineering Handbook*, ITE;
8. *Traffic Control Systems*, National Electrical Manufacturers Association (NEMA);
9. National, State and local electrical codes;
10. *Traffic Detector Handbook*, FHWA;
11. *Traffic Signal Installation and Maintenance Manual*, ITE;
12. *Equipment and Material Standards of the Institute of Transportation Engineers*, ITE;
13. *ITE Journal* (published monthly) ITE; and

14. Manufacturers' literature.

77-1.03 Official Action

Wherever a new traffic signal is installed or an existing traffic signal is removed, an "official action" is required. For State-controlled highways, the designer must obtain an approval for the proposed change from the appropriate district traffic engineer before implementation of the proposed change. For locally controlled facilities, approval must be obtained from the appropriate jurisdiction before starting design. Official actions may also be required where other regulatory controlled items are revised in association with a traffic signal (e.g., no-right-turn-on-red signs).

77-1.04 Project/Plan Development

Chapter Two presents the Department's procedures for preparing a typical traffic signal design project. Chapter Two also indicates the responsible unit for each activity. Part II presents the Department's criteria for developing a set of plans, which are also applicable to traffic signal projects. Part II contains information on scale sizes, CADD requirements, plan sheet requirements, quantities, specifications, etc.

77-1.05 Definitions

The following are definitions for the more commonly used terms in traffic signal design.

1. <u>Controller</u>. A device that controls the sequence and duration of indications displayed by traffic signals.

2. <u>Coordination</u>. The establishment of a definite timing relationship between adjacent traffic signals.

3. <u>Cycle</u>. For pretimed controllers, it is the period of time used to display a complete sequence of signal indications. For actuated controllers, a complete cycle is dependent on the presence of calls on all phases.

4. <u>Cycle Length</u>. The time required for one complete sequence of signal indications.

5. Delay. (1) A measure of the time that has elapsed between the stimulus and the response; (2) traffic delay — the time lost by vehicle(s) due to traffic friction or control devices.

6. Demand. The need for service; for example, the number of vehicles desiring to use a given segment of roadway during a specified unit of time.

7. Detection. The process used to identify the presence or passage of a vehicle at a specific point or to identify the presence of one or more vehicles in a specific area.

8. Detector. A device for indicating the presence or passage of vehicles or pedestrians (e.g., loop detector, microloop detector, push button).

9. Dilemma Zone. A range of distances from the intersection where drivers may react unpredictably to a yellow signal indication (i.e., deciding to stop or to continue through the intersection).

10. Interconnected. The situation where traffic signals, signs and/or computers are designed to work in coordination with each other.

11. Interval. A discrete portion of the signal cycle during which the signal indications remain unchanged.

12. Interval Sequence. The sequence of operation in which the various intervals are displayed during a cycle.

13. Interval Timing. The passage of time that occurs during an interval.

14. Loop Detector. A device capable of sensing a change in the inductance of a loop sensor imbedded in the roadway caused by the passage or presence of a vehicle over the loop.

15. Offset. The time difference or interval in seconds between the start of the green indication at one intersection as related to the start of the green interval at another intersection or from a system time base. May also be expressed in percent of cycle length.

16. Pattern. A unique set of timing parameters (cycle length, split and offset) associated with each signalized intersection within a predefined group of intersections.

17. Phase. A part of the traffic signal cycle length allocated to a combination of traffic or pedestrian movements receiving right-of-way simultaneously during one or more intervals.

18. Phase Overlap. Refers to a phase that operates concurrently with one or more other phases.

19. Phase Sequence. The order in which a controller cycles through all phases.

20. Point Detection. The detection of a vehicle as it passes a point on a roadway.

21. Preemption. The term used when the normal signal sequence at an intersection is interrupted and/or altered in deference to a special situation such as the passage of a train, bridge opening or the granting of the right-of-way to an emergency vehicle.

22. Presence Detection. The ability of a vehicular detector to sense that a vehicle, whether moving or stopped, has appeared in its detection area.

23. Recall. An operational mode for an actuated intersection controller whereby a phase, either vehicular or pedestrian, is displayed each cycle whether the demand exists or not.

24. Signal Head. An arrangement of one or more signal indications in one direction.

25. Signal Indication. The active illumination of a traffic signal lens or equivalent device.

26. Split. A percentage of the cycle length allocated to each of the various phases in a signal sequence.

27. Yield Point. The point at which the controller permits the existing phase to be terminated to service a conflicting phase.

77-2.0 PRELIMINARY DESIGN ACTIVITIES

Typically, the district traffic section is responsible for making the determination on the need for a new or existing traffic signal. This determination is based on several factors including traffic volumes, accident history, schools, pedestrians, local needs, driver needs, construction costs and maintenance costs. The following sections provide information on some of the guidelines, policies, procedures and factors used by INDOT to make these determinations.

77-2.01 Signal Study Requests

Requests for new signals may be generated by many sources — FHWA, the Environment, Planning and Engineering Division's Preliminary Engineering Studies Section, the district traffic section, local officials, developers and/or local citizen groups. All requests for new traffic signal installations should be first forwarded to the appropriate district traffic engineer. If the district traffic engineer determines the request merits further investigation, he or she will then begin coordinating the collection of the necessary traffic data.

For in-house requests, the district traffic engineer, possibly in conjunction with the Environment, Planning and Engineering Division's Environmental Services Section, will conduct the appropriate traffic studies to obtain accurate and up-to-date traffic data and projections. For other requests, the latest traffic data and projections should be forwarded with the request. The data collector will need to refer to the *MUTCD*, which provides the warrants for traffic signals, to determine the appropriate information required. For additional information on the collection of traffic data, the designer should review the ITE publication, *Manual of Traffic Engineering Studies*, or contact the Environmental Services Section.

If it is determined that a traffic signal is warranted, the Design Division's Specialty Project Group, or a consultant, will prepare the design for the proposed traffic signal. The district traffic engineer will be typically responsible for determining the traffic signal timings. In some situations, the local agency or consultant may be responsible for determining the traffic signal timings.

77-2.02 Signal Warrants

All new traffic signals should meet at least one or more of the primary warrants listed below. Supplemental warrants should be considered as an advisory condition and, therefore, do not mandate the installation of a traffic signal. The supplemental guidelines are additional considerations in the determination for the need to install traffic signals. The *MUTCD* traffic signal warrants are as follows:

1. Primary Warrants.

    a. Minimum vehicular volume
    b. Interruption of continuous traffic
    c. Minimum pedestrian volume

2. Supplemental Warrants.

    a. School crossings
    b. Progressive movement
    c. Accident experience
    d. Systems
    e. Combination of warrants

f. New facilities
g. Special access
h. Four-hour volumes

3. Supplemental Guidelines.

a. Peak-hour delay
b. Peak-hour volume

The *MUTCD* provides the actual criteria and procedures that should be used to determine if the warrant is met.

77-2.03 Warrant Analysis

Even though traffic volumes may be sufficiently high to meet one or more of the warrants, the installation of a traffic signal may not always be the most prudent choice. In addition to the *MUTCD* warrants, the following information should be considered.

1. Minimums. The *MUTCD* warrants are considerations for determining the need for a traffic signal. The intent of the *MUTCD* thresholds is to establish a minimum boundary below which a traffic signal should not be installed. Meeting or exceeding these thresholds does not automatically warrant a traffic signal.

2. Benefits. The benefits of the traffic signal must outweigh its disadvantages. Traffic signals will cause delays for at least one leg of the intersection when serving the needs of another. A traffic signal should be installed only if the safety and/or the operations of the intersection or system are improved.

3. Accidents. Traffic signals are often installed to reduce certain types of accidents (e.g., right-angle collisions, pedestrian crossings). However, the installation of a traffic signal may increase the number of rear-end collisions and may fail to reduce turning conflicts between vehicles and pedestrians. Consideration should be given as to whether a change in accident types and their severity will be an actual improvement for the intersection. Accident data for the location should include at least the past three years. Consideration should be given to alternative solutions to the problem of accidents (e.g., removing parking, using bigger signs).

4. Geometrics. The geometric design of the intersection can affect the efficiency of the traffic signal. Installations of traffic signals at poorly aligned intersections may, in some cases, increase driver confusion and thereby reduce the overall efficiency of the

intersection. If practical, the intersection should be properly aligned and have sufficient room to adequately provide turning lanes, through lanes, etc. Chapter Forty-six provides detailed information on the geometric design of at-grade intersections.

5. System Analysis. The control of traffic should be conceived and implemented on a systematic basis -- system/route/intersection. This may sometimes result in compromises at individual intersections in order to optimize the overall system. Traffic signals also may encourage drivers to use local facilities to by-pass the signal. Intersection controls should favor the major streets to move traffic through an area.

6. Location. The designer should consider the intersection relative to the context of the land use, density of development (e.g., urban, suburban, rural) and the potential for future development. The designer should consider the location of the intersection within the context of the transportation system such as isolated locations, interrelated operations, functional classification. Normally, isolated locations are intersections where the distance to the nearest signalized intersection or potential future signalized intersection is greater than 800 m.

7. Existing Signals. For projects which include existing signals, it will rarely be warranted to conduct a detailed study to determine if the existing signal should be removed, retained or upgraded. Typically, this determination will be made during the preliminary field review. If it is determined during the field review that a detailed analysis might be required, the designer should consult with the District Traffic Section to determine if there may be a need to remove the traffic signal.

77-2.04 Responsibilities

It is the Department's policy to fund the design and installation of a traffic signal only where the intersection is on a State-maintained highway or where a freeway exit or entrance ramp intersects with a local facility. For State highways intersecting private drives or roads, or public roads where large traffic volumes are generated from a private source, the private entity will typically be responsible for funding the design, installation and energy costs of the new signal.

All traffic signals on State highways are typically maintained by INDOT or through a contract or agreement with others. Only under rare circumstances will the local municipality, through a formal agreement, assume responsibility for the maintenance of a traffic signal on a State-maintained route.

77-3.0 FLASHERS/FLASHING BEACONS

77-3.01 Guidelines for Hazard Identification Beacons

A hazard identification beacon should only be used to supplement the appropriate warning or regulatory sign or marker. Typical applications include the following:

1. identifying an obstruction in or immediately adjacent to the roadway;

2. as a supplement to advance warning signs (e.g., school crossings);

3. at mid-block pedestrian crossings;

4. at intersections where a warning device is required; and

5. as a supplement to regulatory signs, excluding “Stop,” “Yield,” and “Do Not Enter” signs.

In general, the need for a hazard identification beacon will be determined on a case-by-case basis. The following sections provide additional guidance for the use of hazard identification beacons.

77-3.02 Speed Limit Sign Beacon

A speed limit sign beacon is intended for use with a Speed Limit sign. Where applicable, a flashing speed limit beacon (with an appropriate accompanying sign) may be used to indicate the time periods or conditions in which the speed limit shown is in effect.

A speed limit sign beacon consists of two circular, yellow sections, each having a visible lens diameter of not less than 150 mm or, as an alternative, one or more circular, yellow lenses each having a minimum visible diameter of 200 mm. Where two lenses are used, they should be aligned vertically (i.e., top and bottom of sign). If the sign is longer horizontally than vertically, then the lenses may be aligned horizontally. The beacons should flash alternately. The lenses of the school speed limit beacon may be positioned within the face of the sign itself.

77-3.03 Intersection Control Beacon

Intersection control beacons are intended for use at intersections where traffic or physical conditions do not justify conventional traffic signals, but where conditions indicate a hazard potential. The installation of flashing beacons at an intersection with yellow flashing on the preferential street and red flashing on the stop street may be warranted where two or more of the following conditions exist.

1. Accidents. At intersections with five or more reported accidents during a 12-month period that have a predominance of accident types that may be corrected by cautioning and stopping traffic.

2. Sight Distance. In conjunction with "Stop" signs where sight distance is limited or where other physical or traffic conditions make it especially desirable to emphasize the need for stopping on one street and for proceeding with caution on the other.

3. Traffic Volumes. Where the minimum vehicular volume entering an urban intersection from all directions averages 400 vehicles per hour for any two 1-hour periods of one day and where vehicular traffic entering the intersection from the minor-street approaches averages at least 50 vehicles per hour for the same hours. For rural areas and for communities with populations of 500 or less, the traffic volumes are 70 percent of the urban volumes (i.e., 280 vehicles per hour and 35 vehicles per hour).

4. Speeds. At intersections where excessive speed prevails. This warrant should not be considered where the 85th percentile speed is equal to or less than 70 km/h.

5. Schools. At intersections having at least 50 school children crossing the major approaches as pedestrians, or where 10 school buses each transporting one or more children crossing, turning onto or turning from the major approaches per hour for any two 1-hour periods of one day during regular school arrival and dismissal periods.

Where based on engineering judgment, supplemental beacons may be used at multi-way, stop-controlled intersections. The intersection control beacon should be red for all approaches.

An intersection control beacon consists of one or more sections of a standard traffic signal head, having flashing, circular yellow or circular red indications in each face. Each intersection must have at least two indications for each approach. Indications normally flash alternatingly, but may flash simultaneously. Supplemental indications may be required on one or more approaches to provide adequate visibility to approaching motorists.

77-3.04 Stop Sign Beacon

A stop sign beacon is used to draw attention to the “Stop” sign. The beacon uses one or two sections of a standard traffic signal head with a flashing, circular red indication in each section. The lenses may be either 200-mm or 300-mm in diameter. Where they are aligned horizontally, they should flash simultaneously and, where they are aligned vertically, they should flash alternately. The bottom of the housing for the beacon should normally be located 300 mm to 600 mm above the top of the stop sign.

77-3.05 General Beacon Design

Flashing beacon units and their mountings must meet the general design specifications for traffic control signals. Some of these include the following:

1. Lens. Each signal unit lens should have a visible diameter of at least 200 mm, except for speed limit sign beacons which may be 150 mm. The red and yellow lens must meet the requirements of the ITE *Standard for Adjustable Face Vehicle Traffic Control Signal Heads.*

2. Sight Distance. When illuminated, the beacon should be clearly visible to all drivers it faces for a distance of 400 m under normal atmospheric conditions, unless otherwise physically obstructed.

3. Flashing. The flashing contacts should be equipped with filters for suppression of radio interference. Beacons must flash at a rate of at least 50 but not more than 60 flashes per minute. The illumination period of each flash should be between one-half and two-thirds of the total cycle. Where hazard identification beacons have more than one section, they may be flashed alternately.

4. Hours of Operations. Hazard identification beacons should only be operated during those hours when the hazard or regulation exists (e.g., school openings and closings).

5. Lamp Dimming. If a 150-watt lamp is used in a 300-mm flashing yellow beacon and the flashing causes excessive glare during night operation, an automatic dimming device may be necessary to reduce the brilliance during night operations.

6. Traffic Signals. A flashing yellow beacon used with an advance traffic signal warning sign may be interconnected with a traffic signal controller.

7. Alignment. If used to supplement a warning or regulatory sign, individual flashing beacon units should be horizontally or vertically aligned. The edge of the housing should normally be located no closer than 300 mm outside of the nearest edge of the sign.

8. <u>Location</u>. The obstruction or other condition warranting the beacon will largely govern the location of the beacon with respect to the roadway. If used alone and located at the roadside, the bottom of the beacon unit should be at least 2.4 m, but not more than 4.6 m, above the pavement. If suspended over the roadway, the beacon clearance above the pavement should be at least 5.2 m, but not more than 5.8 m.

77-4.0 TRAFFIC SIGNAL EQUIPMENT

All traffic signal equipment should meet the criteria set forth in the *MUTCD*, NEMA *Traffic Control Systems,* INDOT *Standard Drawings* and INDOT *Standard Specifications.* The following sections provide additional information on traffic signal equipment. For INDOT locations, the equipment choice should be made at the preliminary field inspection with the approval of the designer and the district traffic engineer.

<u>77-4.01 Traffic Controllers</u>

A traffic signal controller is an electrical mechanism mounted in a cabinet for controlling the sequence and phase duration of the traffic signal. Right-of-way is assigned by turning on or off the green indication. There are two basic types of traffic controllers, pretimed and actuated. A pretimed controller operates according to pre-determined schedules. An actuated controller operates with variable vehicular and pedestrian timing and phasing intervals which are dependent upon traffic demands. If there is no demand for a phase, the actuated controller may omit that phase in the cycle (e.g., if there is not a demand for left turns, the left-turn phase will not be activated). The following sections provide general information on the various controllers used by the Department. Section 77-5.0 describes the phasing and timing aspects of the controller.

77-4.01(01) Pretimed Controller

Pretimed controllers use a fixed, consistent predetermined cycle length, usually 60 to 140 seconds. They can be programmed to provide several different timing programs based on the time of day and/or day of week. Pretimed controllers can be either solid-state (electronic) or electromechanical. For all new INDOT installations, only solid-state controllers are used. Existing INDOT or local agency signals may have either an electromechanical or solid-state controller. The solid-state design has better expansion capabilities, is easier to install and is easier to maintain than the electromechanical controller. In addition, replacement parts for electromechanical controllers are difficult to obtain.

Pretimed controllers are best suited where traffic volumes and patterns are consistent from day-to-day (e.g., downtown areas), where variations in volumes are predictable and where control timing can be preset to accommodate variations throughout the day.

The following presents some of the advantages and disadvantages of the pretimed controller:

1. Advantages.

   a. They can be easily incorporated into a progression system.

   b. They are not dependent on a detection device.

   c. They are typically easier to operate than actuated controllers.

   d. They have been commonly used in the past.

   e. They require little additional training of local maintainers for proper operation and maintenance.

2. Disadvantages.

   a. There is not an industry-wide interchangeability standard for replacement parts between different NEMA TS-1 controllers. However, NEMA TS-2 controllers are expected to be interchangeable.

   b. They cannot compensate for unplanned fluctuations in the traffic flows which can cause excessive vehicular delays.

   c. They tend to be inefficient at intersections with random traffic arrivals (e.g., isolated intersections).

Because the cost differential between a pretimed and actuated controller is minimal and actuated controllers can be set up to simulate pretimed controllers, INDOT has limited the use of pretimed controllers on State highways. Any proposed use of a new pretimed controller on a State highway must be approved by the Design Division’s Specialty Project Group.

77-4.01(02) Semi-Actuated Controller

Semi-actuated controllers are based on vehicular detection from one or more approaches, but not on all approaches. Typically, vehicular detectors (e.g., loop detectors) are placed only on the minor approaches where traffic is light and sporadic. The major approaches are kept in the green phase until a vehicle on the minor approach is detected. If there is a demand on the minor approach and the minimum green time for the major approach has elapsed, the right-of-way will then be given to the minor approach. To handle various fluctuations on the minor approach, the minor approach is given enough time to clear one vehicle with additional time added for each new detection up to the maximum green time. Once the minor approach demand has been satisfied or when the maximum green time has been reached, the right-of-way is then returned to the major approach and the cycle begins again. If there is no minor approach demand, the major approach will remain in the green phase indefinitely.

Typical locations for semi-actuated controllers include the following:

1. school crossing intersections,
2. on access routes to industrial areas or shopping centers,
3. on access routes to recreational areas or sport centers,
4. on cross streets with poorly spaced signals along the major route, and/or
5. on cross streets with minimal traffic volumes.

The following are some of the advantages and disadvantages of the semi-actuated controller.

1. <u>Advantages</u>.

   a. The major approach receives a green phase indefinitely until a vehicle is detected on the minor approach. This reduces the mainline delay during periods of light traffic because no green time is given to phases where no traffic demand exists.

   b. They can be easily incorporated into a coordinated system.

   c. They can be effectively used at isolated intersections.

   d. They tend to provide the maximum efficiency at intersections where fluctuation in the side street traffic cannot be anticipated and programmed for with pretimed control.

2. <u>Disadvantages</u>.

   a. Short, continuous demands on the minor street (e.g., factory shift changes) can cause excessive delays to the mainline.

   b. A detection device is required, typically loop detectors on the minor street.

   c. They are typically more complex to operate than pretimed controllers.

d. There is no dilemma zone protection for any of the approaches. Consequently, they should not be used where the posted approach speeds are greater than 60 km/h. Section 77-5.08 further defines the dilemma zone requirements.

INDOT typically uses a fully actuated controller to simulate the semi-actuated intersection.

77-4.01(03) Fully Actuated Controller

A fully actuated controller has detection devices on all approaches to the signalized intersection. The green interval for each street or phase is determined on the basis of volume demand. Continuous traffic on one street is not interrupted by an actuation demand from the side street until a gap in the traffic appears or when the preset maximum green time has elapsed. Once the minor street demand has been satisfied, right-of-way is typically returned to the major street whether or not a major street detection has been registered. Where there is a continuous demand on all approaches, the intersection tends to operate as a pretimed system.

A fully actuated controller is an appropriate design choice as follows:

1. at isolated locations where volumes on intersection legs are more equal with sporadic and varying traffic distribution,

2. at locations where traffic signal control is warranted for only brief periods of the day,

3. at locations where turning movements are heavy only during specific time periods and are light the remainder of the time, and/or

4. at locations where the posted speeds are greater than 60 km/h and where there is a need to avoid “dilemma zone” problems (see Section 77-5.08).

The following are some of the advantages and disadvantages of a fully actuated controller.

1. <u>Advantages</u>.

   a. They can handle high traffic volumes.

   b. They are very efficient at isolated intersections.

   c. They can handle varying traffic demands (e.g., complex intersections where one or more movements are sporadic or subject to variation in volume).

d. They can be programmed to operate as a pretimed signal or semi-actuated system.

e. They can be programmed to allow different phases to operate concurrently, if they are not conflicting phases.

f. Mainline delay during periods of light traffic is reduced because no green time is given to phases where no traffic demand exists.

2. Disadvantages.

a. A detection device is required on all approaches, typically loop detectors.

b.. They are more complex to operate.

77-4.01(04) Actuated Controller with Density Feature

The density feature is an enhancement to the actuated controller. Additional detectors are placed in advance of the intersection to determine both the number of vehicles waiting and vehicular gaps. The density feature allows the controller to adjust the initial portion of the green time to account for the queue of waiting vehicles arriving during the yellow and red phases to clear the intersection. Once the initial queue is cleared, the allowable mainline vehicular gap is reduced over time giving greater priority to conflict calls from the side streets. When the gaps on the mainline are too long or the preset maximum green time has passed, the right-of-way is then given to the side streets to allow the waiting vehicles a chance to enter or cross the highway. The following are some of the advantages and disadvantages of the density feature.

1. Advantages.

a. They are very efficient at high-speed intersections.

b. They can effectively handle large traffic volumes.

c. They can effectively clear stored traffic (e.g., stored vehicles in a left-turn bay).

d. They can be programmed to give higher priority to the mainline.

e. They can be programmed to allow different phases to operate concurrently, if they are not conflicting phases.

f. They can be programmed to handle specific local site conditions.

2. Disadvantages.

a. Additional detection devices are required.

b. They are more complex to operate.

c. Typically, they have higher initial costs.

INDOT requires that all new controller installations on State highways include the density feature. Where it is deemed unnecessary, the designer needs to obtain approval from the Design Division's Traffic Design Unit before it can be removed from the project.

77-4.01(05) Pedestrian Feature

The pedestrian feature commonly works in conjunction with the signal controller. This feature allows for the timing of the Walk and Don't Walk cycles and can be actuated by pedestrian push buttons. The following are some of the advantages and disadvantages of the pedestrian feature.

1. Advantages.

a. It provides additional time for crossing pedestrians.

b. Where there is minimal pedestrian demand, disruption to the vehicular phases can be minimized.

2. Disadvantages.

a. Where pedestrian push buttons are required, they must be located in a convenient, accessible location.

b. Pedestrian cycles concurrent with green time may marginally delay right-turning vehicles.

c. They can significantly increase the required minimum green time on the minor street if the major street is substantially wider than the minor street.

77-4.01(06) Controllers with Specialty Features

There are several other specialty features that may be used in traffic engineering designs (e.g., flashing beacons, emergency vehicle actuations, railroad grade-crossing signals). The use of these features is site specific and should be used on a case-by-case basis.

77-4.01(07) Controller Design Concepts

There are two basic design concepts for controllers, NEMA and Type 170. The National Electrical Manufacturers Association (NEMA) controllers have standard functions and input/output formats, but use different electronic techniques, including microprocessing, to provide the functions. NEMA controllers are intended to be interchangeable between manufacturers. Where changes or upgrades to the controller are desired, the controller unit hardware is typically replaced. The Model 170, developed by the States of California and New York, defines the hardware requirements and uses a general purpose microprocessor. Changes for individual intersections vary with the software applications. Where changes are required, the Type 170 controller software is rewritten and the hardware is retained. Figure 77-4A presents the advantages and disadvantages of NEMA and Type 170 controllers.

INDOT uses the NEMA criteria for all of its traffic signal controllers. At a minimum, all INDOT-maintained traffic controllers must meet the INDOT *Standard Specifications* and NEMA TS-1 criteria. Desirably, new traffic controllers should include some of the enhancements of the NEMA TS-2 criteria. A list of all approved controller equipment is provided in the Department's *List of Approved or Prequalified Materials*. All approved controllers must meet the Department's *Traffic Signal Control Bench Test Procedures*. A copy of the list of approved controllers may be obtained by contacting the Contracts and Construction Division's Contracts Services Section.

The NEMA controller can either be a single-ring controller or a dual-ring controller depending on the number of phases the intersection will have. Section 77-5.06 provides information on the selection of phases for an intersection. Single-ring controllers are used where the conflicting phases are established in a set order. Figure 77-4B, Sequence of Phases, detail A illustrates the appropriate phasing sequence for single-ring controllers. A dual-ring controller unit contains two interlocking rings that are arranged to time in a preferred sequence and to allow concurrent timing of both rings, subject to the restraint of the barrier. For the controller to advance beyond the barrier, both sets of rings must cross the barrier line at the same time (i.e., no conflicting phase may be shown at the same time). Figure 77-4B, detail B illustrates the sequence of phases for an 8-phased, dual-ring controller.

77-4.01(08) Associated Controller Equipment

Each controller unit will require a power supply, surge protectors, load switches and conflict monitor. This equipment must meet or exceed the Department's "Traffic Signal Control Bench Test Procedures" and the NEMA TS-1 criteria. Auxiliary equipment that can be added to the controller, depending on the intersection, includes preemptors, coordinators and detectors. Where used, this auxiliary equipment must also meet both the INDOT *Standard Specifications* and NEMA criteria. Section 77-4.01(11) discusses preemption, Section 77-4.02 detectors and Section 77-6.0 system coordination.

77-4.01(09) Conflict Monitor

With solid-state equipment, there is a potential for the accidental display of erroneous indications (e.g., greens for conflicting movements). Typically, the problem will be with the solid-state load switch, which switches the electrical current to the signal indications on and off. To protect against failure, all solid-state controllers must have a conflict monitor.

77-4.01(10) Controller Cabinets

Controller cabinets are enclosures designed to house the controller unit and its associated equipment, providing for its security and environmental protection. All controller cabinets must meet the criteria in the INDOT *Standard Specifications* including material types, sizes, locks, police doors, outlets, ventilating fan, etc. Section 77-5.02 presents considerations for the placement of the cabinet relative to roadside safety. Foundation requirements for each cabinet type are shown in the INDOT *Standard Drawings.* The following discusses the various cabinet types used by the Department.

1. G Cabinet. The G cabinet is a pedestal-mounted or pole-mounted cabinet. In general, the Department no longer uses this cabinet due to its limited size. However, this cabinet type may be used, if practical, for matching or upgrading existing local signals.

2. M Cabinet. The M cabinet is a ground-mounted cabinet. This cabinet is used with a 4-phase or smaller controller. Where there is a possibility that more phases may be necessary in the future, the P-1 cabinet should be used.

3. P-1 Cabinet. The P-1 cabinet is a ground-mounted cabinet. This cabinet is the preferred Department cabinet. It is typically used with an 8-phase controller. If used for a 4-phase or smaller controller, it allows for the possible upgrade with minimum effort.

77-4.01(11) Preemption

Preemption is the modification of a traffic signal’s normal operation to accommodate a special occurrence, such as the approach of an emergency vehicle, the passage of a train through a grade crossing or the opening of a drawbridge. Another form of preemption can also be used to provide priority to transit vehicles by minimizing the delays to these vehicles. Preemption sequences should be shown in the contract plans or in the special provisions. For information on preemption equipment, the designer should contact the manufacturer. The following describes several situations where preemption is typically used.

1. <u>Railroad Crossing Preemption</u>. The preemption of signal operations caused by the passage of a train is probably the most common use of preemption equipment. Where a signalized intersection is within 60 m of a railroad grade crossing, preemption is used to eliminate the potential for conflicting instructions from the railroad crossing signals and intersection signals. The *MUTCD* describes several preemption strategies and define the requirements for grade-crossing preemption.

   Railroad preemption requires interconnection between the traffic signal controller and the grade-crossing signal equipment. The preemption routine at the traffic signal controller is initiated by the approach of a train, as detected by the railroad’s controller, and typically starts with a short track clearance phase, to clear motorists who may be stopped between the railroad crossing stop bar and the intersection. Subsequent signal displays include only those that would not be in conflict with the occupied grade crossing. When the train has passed, the signal is returned to normal operations. On State routes, this type of preemption typically requires an agreement between the State and the railroad.

2. <u>Fire Station / Fire Route Preemption</u>. There are several forms of fire station or fire route preemption. The common denominator for this category is the activation of the preemption sequence at some fixed point (e.g., a push button located within the firehouse).

   The simplest form of fire station preemption is the installation of an emergency signal, typically at the fire station driveway intersection with a major through street. Using essentially a 2-phase, semi-actuated controller, the signal dwells in the through-street display (green or flashing yellow) until called by an actuation in the fire station. The signal then provides a timed right-of-way to the driveway to allow emergency vehicles to enter or cross the major street.

Where the fire station is near a signalized intersection, a preemption sequence can be designed to display a special movement permitting the passage of emergency equipment through the intersection. On State routes, this type of preemption typically requires an agreement between the State and the appropriate local governmental agency.

Where emergency vehicles frequently follow the same route through more than one nearby signal, it may be desirable to provide a fire route-preemption operation. Actuation of the fire station push button will be transmitted to all the signals along the route and, after a variable timed delay, each signal will provide a preempt movement display. This will provide a one-way “green wave” away from the fire station, allowing the optimal movement of emergency equipment.

3. <u>Moving Emergency Vehicle Preemption</u>. A number of devices are available to permit the preemption of signals by moving emergency vehicles. In each case, the preemption equipment causes the signals to advance to a preempt movement display. On State routes, this type of preemption typically requires an agreement between the State and the appropriate local governmental agency.

One system of identifying the presence of the approaching emergency vehicle uses a light emitter on the emergency vehicle and a photocell receiver for each approach to the intersection. The emitter outputs an intense strobe light flash sequence, coded to distinguish the flash from lightning or other light sources. The electronics package in the receiver identifies the coded flash and generates an output that causes the controller unit to advance through to the desired preempt sequence.

A second type of system uses a low-power radio transmitter on the emergency vehicle and a radio receiver at each intersection to be preempted. The driver of the vehicle activates a dashboard switch based on the heading of the vehicle, north and south or east and west. This switch codes the radio transmission, and the intersection receiver can implement the appropriate preempt sequence. One system using this technique includes a compass-based switch in the emergency vehicle. It can also encode the vehicular identification number for preemption logging purposes.

Both of these systems require a specialized transmitting device on each vehicle for which preemption is desired, and they require that drivers activate the transmitters during their run and turn off the transmitters after arriving at the scene.

A third system uses a receiver at the intersection that senses the emergency vehicle’s siren to initiate preemption. This system cannot provide directionality of approach; however, it can be used to start a predetermined preemption sequence or intersection flash.

4. <u>Transit Vehicle Preemption</u>. Most transit-preemption systems are designed to extend an existing green indication for an approaching bus and do not cause the immediate termination of conflicting phases, as would occur for emergency vehicle preemption. On State routes, this type of preemption typically requires an agreement between the State and the appropriate local governmental agency.

   Two transit vehicle preemption systems are very similar to the moving emergency vehicle-preemption systems. One system is a light emitter/receiver system, using the coded, flash-strobe light emitter. An infrared filter is placed over the emitter, so that the flash is invisible to the human eye, and a special flash code is used to distinguish the transit preemption call from that for an emergency vehicle. The intersection receiver can be configured to provide both emergency vehicle and transit preemption with the same equipment. The second system uses the same type of radio transmitter/receiver equipment as used for emergency vehicle preemption.

   Two other types of transit vehicle detectors have been used and are available. One, denoted a "passive" detector, can identify the electrical "signature" of a bus traveling over an inductive loop detector. The other, an "active" detector, requires a vehicle-mounted transponder that replies to a roadside polling detector.

5. <u>Preemption Equipment</u>. With microprocessor-based controllers, virtually all preemption routines are performed by the controller software. The only necessary external equipment is the preemption call detection device. In controllers built to NEMA standards, internal preemption capability is provided as an option and may require a special module. Several manufacturers provide a set of preemption routines that can be tailored to virtually any intersection's preemption scheme. Others may require a factory-designed sequence, burned into memory for the requirements of a specific intersection.

<u>77-4.02 Detectors</u>

77-4.02(01) Operation

The purpose of a detector is to determine the presence of a vehicle, bicyclist or pedestrian, or the passage of a moving vehicle. This presence or passage detection is sent back to the controller which adjusts the signal accordingly. There are many types of detectors available that can detect the presence or passage of a vehicle. Typically, INDOT only uses the inductive loop detectors in its signal design. The inductive loop detector is preferred because it can be used for passage or presence detection, vehicular counts, speed determinations, and it is generally accurate and easy to maintain. Although the inductive loop detector is usually the system of choice, this does not prevent the designer from recommending the use of new devices in the future. If, in the designer's opinion, a different detector should be considered, its use must be first coordinated with the Design Division's Specialty Project Group and the district traffic engineer to detail any special maintenance requirements or equipment needs.

In most cases, the controller detection device can operate in several different modes. The following discusses several of these modes.

1. <u>Passage (Pulse) Detection</u>. Passage detectors detect the passage or movement of a vehicle over a given point. They submit a short-duration (pulse) output signal. The short loop design (short detection area) is considered to be a passage detector.

2. <u>Presence Detection</u>. Presence detectors register a detection when a vehicle is stopped or is within the detection area. A signal output is generated for as long as the detected vehicle is within the monitored area (subject to the eventual tuning out of the call by some types of detectors). The long loop design (long detection area) is considered to be a presence detector.

3. <u>Locking Mode</u>. The detector or the controller memory holds a call in the waiting phase until the call has been satisfied by a green display even though the calling vehicle may have already vacated the approach (e.g., a vehicle turning right on red).

4. <u>Non-locking Mode</u>. For non-locking operations, the call is only held while the detector is occupied. The call is voided when the vehicle leaves the detection area. The non-locking mode is typically used with presence detectors (e.g., with permissive left-turn lanes).

5. <u>Delayed Detection</u>. Delayed detection requires the vehicle to be located in the detection area for a certain set time before a detection is recorded. If a vehicle leaves the area before the time limit is reached, no detection is noted. This application is appropriate where right-turns-on-red are allowed.

6. <u>Extended-Call or Stretch Detection</u>. With extended-call detection, the detection is held by the detector even after a vehicle has left the detection area. This operation is typically performed to hold the call until the passing vehicle has time to reach a predetermined point beyond the detection zone. With solid-state controllers, the extended-call detections are typically handled by the controller software.

Where the controller is part of a coordinated signal system design, special care will be required when using extended or delayed detections to ensure that the local controller will not adversely affect the timing of the system.

77-4.02(02) Inductive Loop Detector

An inductive loop detector (loop detector) design consists of two or more turns of wire embedded in the pavement surface. INDOT uses four turns. As a vehicle passes over the loop, it disrupts the current running through the wire. This disruption is recorded by an amplifier and is transmitted to the controller as a vehicular detection. NEMA criteria define the requirements for both self-contained loop-detector units (shelf mounting) and for card-type detector units (inserted into a multi-slotted card rack wired in the cabinet). The NEMA criteria also define optional timing features that can be used for loop detectors, including delaying or extending the detector output.

The advantages of loop detectors are as follows:

1. detect vehicles in both presence and passage modes,
2. be used for vehicular counts and speed determinations, and
3. be easily designed to meet the various site conditions.

A major disadvantage of the loop detector is that it is very vulnerable to pavement surface problems (e.g., potholes) which can cause breaks in the loops. To alleviate this problem, a sequence of loops should be used.

There are basically two types of loop detector designs: the long loop rectangular design (1.8 m x 6 m to 20 m) and the short loop octagonal design (1.8 m x 1.8 m). INDOT normally uses the short loop design. To emulate the long loop detection, a series of short loops are wired in series. The INDOT *Standard Drawings* illustrate typical loop layouts and installation details. The designer needs to be aware that the typical layout shown in the INDOT *Standard Drawings* is for illustrative purposes only. Each intersection should be designed individually to meet local site conditions.

A sequence of loops is used at the intersection itself for presence detection of vehicles stopped at the traffic signal. A set of loops before the intersection is used to determine the passage of vehicles. The distance from the stop bar to these loops is based on the posted speed limit. Sections 77-5.07 and 77-5.08 provide additional information on detector locations.

77-4.02(03) Other Detector Types

There are numerous types of vehicular detectors available. However, INDOT typically uses the inductive-loop detector. The following discusses several other detector types that are available.

1. Magnetic Detector. Magnetic detectors consist of a small coil of wires located inside a protective housing embedded into the roadway surface. As vehicles pass over the device, the detector registers the change in the magnetic field surrounding the device. This signal is recorded by an amplifier and relayed back to the controller as a vehicular detection. A major problem with this detector is that it can only detect the passage of a vehicle traveling at speeds of 5 km/h or greater. It cannot be used to determine a stopped vehicle's presence. The advantages are that they are simple to install and are resistant to pavement-surfacing problems.

2. Magnetometer Detector. A magnetometer detector consists of a magnetic metal core with wrapped windings, similar to a transformer. This core is sealed in a cylinder about 25 mm in diameter and 100 mm long. The detector is placed in a drilled vertical hole, about 300 mm deep in the pavement surface. Magnetometer detectors sense the variation between the magnetic fields caused by the passage or presence of a vehicle. The signal is recorded by an amplifier and is relayed to the controller as a passage or presence vehicle. Magnetometer detectors are sufficiently sensitive to use to detect bicyclists or as a counting device. A problem with the magnetometer detector is that it does not provide a sharp cutoff at the perimeter of the detection vehicle (i.e., it may detect vehicles in adjacent lanes).

3. Microloop Detector. A microloop detector is similar to the magnetometer detector, but it can work with the standard inductive loop detector electronic units. The microloop is typically installed by drilling a 75-mm diameter hole 500 mm deep into the pavement structure or by securing it to the underside of a bridge deck. A major disadvantage of the microloop detector is that it requires some motion to activate the triggering circuitry of the detector and does not detect stopped vehicles. This type of detector would typically require two detectors placed side-by-side due to its limited field of detection.

4. Video Image Detection. The video image detector consists of one to six video cameras, an automatic control unit and a supervisor computer. The computer detects a vehicle by comparing the images from the camera(s) to those stored in memory. The detector can work in both the presence and passage modes. This detector also allows the images to be used for counting and vehicular classification. Special housings are required to protect the camera from environmental elements. Early models experienced problems with the video detection during adverse weather conditions (e.g., fog, rain, snow).

77-4.02(04) Pedestrian Detectors

The most common pedestrian detector is the pedestrian push or call button. These pedestrian call buttons should be placed so they are convenient to use, reachable by the handicapped and not placed in the direct path for the blind. Inconvenient placement of pedestrian detectors is one of the reasons pedestrians may choose to cross the intersection illegally and unsafely.

77-4.02(05) Bicycle Detectors

The two most common methods for bicycle detection include the following:

1. Pedestrian Push-Button Detector. With the push-button detector, the bicyclist must stop and push the detector button for the controller to record the detection. This may require the bicyclist to leave the roadway and proceed on the sidewalk to reach the detector.

2. Inductive-Loop Detector. The inductive-loop detector can detect the bicycle without the bicyclist's interaction. For the greatest sensitivity of the detector, the bicyclist should be guided directly over the wire. A problem with bicycle inductive-loop detectors is that they require a significant amount of metal to be activated. Today's bicycle designs tend to use a substantial amount of non-magnetic, man-made materials to increase their strength and reduce their weight. This has substantially reduced the metal content that can be detected.

77-4.03 Signal Mounting

Under most circumstances, the Department's preferred practice is to install the traffic signal using span, catenary and tether cables, or cantilever structures in a box design (i.e., poles on all four corners). Pedestal- or post-mounted signals may be used if there is a left-turn signal in a median, or on the near side of the intersection if the intersection is significantly wide, or for pedestrian signals. Figure 77-4C, 77-4D, and 77-4E present the advantages and disadvantages of the post-mounted signal, cable-span signal mounting, and the cantilever signal mounting, respectively.

For span designs, steel strain poles should generally be used. Steel strain poles provide greater strength, are easier to maintain and require less space. Wood poles require the use of down-guy cables. Therefore, wood poles are generally limited to areas with sufficient right-of-way (e.g., rural areas) and for temporary installations. The INDOT *Standard Drawings* and the INDOT *Standard Specifications* provide the criteria for both steel and wood poles and for attachments to the pole.

All cantilever structures must be designed to meet the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.*

Overhead highway lighting may be provided, where warranted (see Section 78-2.0), at rural signalized intersections. The traffic signal span-support pole or the cantilever pole may be used for the overhead highway lighting. Figure 77-4F provides an illustration of a combination signal-luminaire pole. The INDOT *Standard Specifications* present the design criteria for this signal pole. INDOT typically does not use combination poles.

77-4.04 Signal Display

The traffic signal display consists of many parts including the signal head, signal face, optical unit, visors, etc. The criteria set forth in the *MUTCD*, the INDOT *Standard Specifications, and* ITE's *Equipment and Material Standards of the Institute of Transportation Engineers* should be followed when determining appropriate signal display arrangements and equipment. The following provides additional guidance for the selection of the signal display equipment:

1. Signal Head Housings. Signal head housings can be made from either aluminum or polycarbonate. Polycarbonate (plastic) is usually lighter and retains its color throughout its service life. However, plastic is not as strong as aluminum and tends to break when used in top- or bottom-mounted rigid installations.

2. Signal Faces. Section 77-5.01 presents INDOT's preferred signal face arrangements for use on State highways. It is INDOT's practice to place the signal lenses in a vertical line rather than horizontally except where overhead obstructions may limit visibility. Where protected left turns are followed by permissive left turns, the five-section signal head is the recommended arrangement choice. The *MUTCD* provides additional information on the arrangement of signal heads.

3. Lens Sizes. Although a 200-mm lens size is allowed by the *MUTCD*, INDOT's preferred practice is to use only 300-mm lenses. INDOT specifications require the use of plastic lenses in its signal displays.

4. Signal Illumination. Relative to signal illumination, the designer should consider the following.

    a. Incandescent. Incandescent bulbs should only be used for solid yellow indicators. The designer is referred to ITE's *Equipment and Material Standards of the Institute of Transportation Engineers* for INDOT criteria on signal lamps. The ITE publication covers lamp illumination, light center length, rated "initial" lumens, lamp life and operating voltages.

b. Light-Emitting Diode (LED). LEDs should be used for all other indicators, including flashing yellow. LED designs use less energy and have a longer life expectancy than incandescent bulbs. The use of all new signal illumination designs should be first coordinated with the Design Division's Specialty Project Group.

5. Reflectors. The reflector directs the light output from the lamp forward through the signal lens. The reflector has a parabolic shape and is designed for the lamp filament. Reflectors are available in three materials: mirrored glass, specular anodized aluminum, and metalized plastic. INDOT specifications require the use of Specular Alzak Aluminum reflectors.

6. Visors. INDOT practice is to use a visor on all signals. These visors are typically used for two purposes -- to direct the signal indication to the appropriate approaching traffic and to reduce "sun phantom." Tunnel visors provide a complete circle around the lens. Cutaway visors are partial visors, typically with the bottom cutaway. Partial visors reduce water and snow accumulation and do not let birds build nests within the visor. The decision on which visor type that should be used is determined on a site-by-site basis. For Department installations, INDOT normally uses partial visors. Visors are made of the same material as the housing.

7. Louvers. Louvers are sometimes used to direct the signal indication to a specific lane (e.g., left-turn signal for a left-turn bay). Louvers are used where several signal heads may cause confusion for the approaching driver. One example of this problem is where a left-turn signal indication is red, but the through lane indications are green. The decision on whether to use louvers depends on site conditions and will be determined on a case-by-case basis.

8. Optically Programmable Signals. Like louvers, optically programmable signals are designed to direct the signal indication to specific approach lanes and for specific distances. A major advantage is that they can be narrowly aligned so that other motorists cannot see the indication. Typical applications include closely spaced intersections, left-turn signals at skewed intersections and left-turn signals on high-speed approaches. Optically programmable signals require rigid mountings to keep the indicator properly directed. Although the initial cost may be higher than louvers, the advantage of being less confusing often makes them cost effective. The decision on whether to use an optically programmable signal depends on site conditions and will be determined on a case-by-case basis.

9. Backplates. A signal indication may lose some of its contrast value when viewed against a bright sky or other intensive background lighting (e.g., advertising lighting). Backplates placed around the signal assembly can enhance the signal's visibility.

However, backplates add weight to the signal head and can increase the effect of wind loading on the signal. The decision on whether to use backplates depends on site conditions and will be determined on a case-by-case basis.

77-5.0 TRAFFIC SIGNAL DESIGN

77-5.01 Design Criteria

In general, INDOT has adopted the *MUTCD* criteria for the placement and design of traffic and pedestrian signals. This includes, but is not limited to, signal indications, color requirements, number of lenses per signal head, number and location of signal heads, height of signal heads, location of signal supports, etc. In addition to the *MUTCD*, the INDOT *Standard Drawings*, and the references in Section 77-1.01, the following sections provide further details and information on the design of traffic signals.

77-5.01(01) Signal Displays

The *MUTCD* requires that there be at least two signal indications for each through approach to an intersection or other signalized location. A single indication is permitted for control of an exclusive turn lane, provided that this single indication is in addition to the minimum two for through movements.

Supplemental signal indications may be used if the two signal indications are marginally visible or detectable. Typical situations where supplemental indications may improve visibility include the following:

1. approaches in excess of three through lanes,
2. locations where there may be driver uncertainty,
3. where there are a high percentage of trucks which may block the signal indications, and/or
4. where the approach alignment affects the continuous visibility of normally positioned signal indications (e.g., left turns beyond the signal indication).

The following figures illustrate the typical INDOT placement for signal heads.

1. Figure 77-5A - multi-lane highway with an offsetting intersection.

2. Figure 77-5B - urban street with parking on the far side and a near side left-turn lane.

3. Figure 77-5C - urban street with parking on the near side, no left-turn lane.

4. Figure 77-5D - left-turn lane with permissible left turns (i.e., no separate left-turn phase).

5. Figure 77-5E - left-turn lane with protected left turns (3 section head).

6. Figure 77-5F - left-turn lane with both protected and permissible left turns (5-section head). Figure 77-5F also illustrates the INDOT preferred method of the 5-section head (i.e., the clustered or doghouse display).

7. Figure 77-5G - multi-lane approach with a left-turn lane.

8. Figure 77-5H - multi-lane approach with both left- and right-turn lanes.

77-5.01(02) Visibility Requirements

The minimum visibility for a traffic signal is defined as the distance from the stop bar at which a signal should be continuously visible for various approach speeds. Figure 77-5 I provides the *MUTCD* minimum visibility distances. If these visibility distances cannot be met, then an advance warning sign should be used to alert the approaching drivers of the upcoming signal.

Vertically, a driver's vision is limited by the top of the vehicle's windshield. This restriction requires the signal to be located far enough beyond the stop bar to be seen by the driver. The *MUTCD* requires a minimum distance of 12 m from the stop bar. The lateral location of the indication should be in the driver's cone of vision. Research indicates that this cone of vision should be desirably within 5^o on either side of the center line of the eye position (i.e., a cone of 10^o). The *MUTCD* requires that at least one and preferably two signal faces be located within 20^o on each side of the center of the approach lanes extended (i.e., a cone of 40^o). There may be confusion on where to measure the center of the approach lanes for multi-lane approaches.

Figure 77-5J, Vision Cone, illustrates INDOT's interpretation of this requirement. In general, the parking lanes should not be included in this determination, but the right- and left-turn lanes are included.

The following discusses several other requirements that should be met when determining the location of signal indications.

1. Where a signal indication is meant to control a specific lane or lanes of approach, its position should make it readily visible to the drivers making the specific movement.

2. Near-side signal heads should be located as near as practical to the stop line.

3. Signal heads for any one approach should be mounted no less than 3.0 m apart between the center of the heads, measured perpendicular to the direction of travel.

4. Where practical, at least one (and preferably both) signal head that controls through traffic should be located not less than 12 m nor more than 45 m beyond the stop line.

5. Where the nearest signal head is more than 36.5 m, but 45 m or less beyond the stop line, a 300-mm signal indication or a supplemental near-side signal head should be used. It is INDOT’s preferred practice to only use 300-mm lenses on State highways. Where the nearest signal head is more than 45 m beyond the stop line, a supplemental near-side signal head should be used.

77-5.02 Placement of Signal Equipment

For the most part, the designer has limited options available in determining acceptable locations for the placement of signal pedestals, signal poles, pedestrian detectors and controllers. Considering roadside safety, these elements should be placed as far back from the roadway as practical. However, due to visibility requirements, limited mast-arm lengths, limited right-of-way, restrictive geometrics or pedestrian requirements, traffic signal equipment often must be placed relatively close to the travelway. The designer should consider the following when determining the placement of traffic signal equipment.

1. Clear Zones. If practical, the placement of traffic signal equipment on new construction and reconstruction projects should meet the clear zone criteria presented in Section 49-2.0. For 3R projects, they should be located outside of the obstruction-free zone; see Section 55-5.02. New signal installation projects on existing routes or signal modernization projects are considered to be 3R projects.

2. Controller. In determining the location of the controller cabinet, the designer should consider the following:

    a. The controller cabinet should be placed in a position so that it is unlikely to be struck by errant vehicles. It should be outside the clear zone or obstruction-free zone.

b. The controller cabinet should be located where it can be easily accessed by maintenance personnel.

c. The controller cabinet should be located so that a technician working in the cabinet can see the signal indications in at least one direction.

d. The controller cabinet should be located where the potential for water damage is minimized.

e. The controller cabinet should not obstruct intersection visibility.

f. The power service connect should be reasonably close to the controller cabinet.

3. Traffic Signal Supports. Traffic signal supports should be placed to provide the obstruction-free zone through the area where the traffic signal supports are located. However, the following exceptions will apply:

a. Channelized Islands. Installation of signal supports in channelizing islands should be avoided, if practical. However, if a signal support must be located in a channelizing island, a minimum clearance of 9.0 m should be provided from all travel lanes (including turn lanes) in rural areas and in urban areas where the posted speed is greater than 70 km/h. In urban areas where the island is bordered by a barrier curb and the posted speed is 70 km/h or less, a minimum clearance of 3.0 m should be provided from all travel lanes (including turn lanes).

b. Non-Curbed Facilities (Posted Speeds $\geq$ 80 km/h and ADT > 1500). Where conflicts exist such that the placement of the signal supports outside of the obstruction-free zone is impractical (e.g., conflicts with buried or utility cables), the signal supports should be located at least 3.0 m beyond the outside edge of the paved shoulder.

c. Non-Curbed Facilities (Posted Speeds < 80 km/h or ADT $\leq$ 1500). Where conflicts exist such that the placement of the signal supports outside of the obstruction-free zone is impractical (e.g., conflicts with buried or utility cables), the signal supports should be located at least 2.0 m beyond the outside edge of the paved shoulder.

d. Curbed Facilities. For curbed facilities, see Section 55-5.02. For facilities with curbs less than 150 mm in height, see Items 3a. and 3b. above.

4. <u>Pedestrians</u>. If the signal pole must be located in the sidewalk, it should be placed to minimize pedestrian conflicts. In addition, the signal pole shall not be placed in a manner that will restrict a handicapped individual's access to curb ramps. Pedestrian call buttons must be conveniently located. Section 51-1.0 provides INDOT criteria for handicapped accessibility.

77-5.03 Pedestrian Signals

All pedestrian signal installations on INDOT projects must meet the criteria in the INDOT *Standard Specifications*. For local facilities, pedestrian signal installations should meet ITE criteria and local practice. Locations where visually-impaired pedestrians are anticipated may warrant the supplemental use of an audible pedestrian signal. The use of audible signals will be determined on a site-by-site basis.

77-5.04 Pavement Marking and Signing

Cantilevers and span cables often contain regulatory and informational signs (e.g., Left-Turn Lane Only, Main Street). The designer should consider the effect the weight of the sign and additional wind loading will have on the cantilever or the span cables. The designer should strive to limit the number of signs on traffic signal structures. Chapter Seventy-five presents additional guidance on the placement and design of signs.

Chapter Seventy-six presents the criteria for the application of pavement markings at intersections. In general, pavement markings are used to supplement the traffic signal indication and lane use signs.

77-5.05 Electrical System

The electrical system consists of electrical cables or wires, connectors, conduit, handholes, etc. Electrical connections between the power supply, controller, detectors and signal poles are typically carried in conduit. The designer should consider the following when developing the traffic signal wiring plan.

1. <u>Service Connections</u>. Service connections from the local utility lines should go directly to the service disconnect and then to the controller; the lines should be as short as practical. These installations will be placed underground in separate conduits from other

signal wires. Easy access to a shut-off device in the controller is required to turn the power supply off when performing system maintenance.

2. Electrical Cables. All electrical cables and connections must meet national, state and local electrical codes, in addition to the NEMA criteria, except for the green wire, which is used for the green indication or interconnect function and not for the system ground. In general, the number of conductor cables should be kept to a minimum, usually only 3 or 4 combinations, to reduce inventory requirements. Typically, a 7-conductor cable is used between the controller and disconnect hangers or cantilever base. A 5-conductor cable is used between the disconnect hanger or cantilever base and the signal indications. Connections to flashers generally only use a 3-conductor cable. The INDOT *Standard Drawings* illustrate the correct procedures for wiring and splicing cables.

3. Cable Runs. All electrical cable runs should be continuous between the following:

   a. controller to base of cantilever structure or pedestal,
   b. controller to disconnect hangers,
   c. base of cantilever structure or disconnect hanger to signal indications, and
   d. controller to detector housing.

4. Handholes. Handholes should be located adjacent to the controller cabinet, each signal pole and each detector location. The INDOT *Standard Drawings* provide additional details on the design of handholes and wiring details. The maximum spacing between handholes is typically 75 m.

5. Underground Conduit. Underground conduit is used to connect the controller, traffic signals and loop detectors together. Most conduits run underneath the pavement and between the handholes, typically using a 50-mm diameter conduit. For runs with additional cables, the conduit size may need to be increased. The national electrical codes should be checked to determine the appropriate conduit size for the number of electrical cables that can be contained within the conduit. The INDOT *Standard Drawings* provide additional details on the design and placement of underground conduit.

6. Grounding. All metal poles, cantilever structures, controller cabinets, etc., must be grounded. The INDOT *Standard Drawings* illustrate the correct procedures for grounding these devices.

7. Detector Housing. Detector housings should be cast-aluminum boxes encased in concrete. The detector housings are used to splice the 1C/14 wires from the loop(s) to the 2C/16 lead-in cable to the detector amplifier. The INDOT *Standard Drawings* provide additional information on the detector housings, including wiring details.

8. <u>Disconnect Hangers</u>. Disconnect hangers are used for cable-span mounted signals to provide a junction box between the signal heads and the controller.

9. <u>Loop Tagging</u>. All loop detector cables should be tagged in the controller box to indicate which loop detector wire belongs to which loop detector. They should be labeled according to street, direction, lane and distance from the stop line.

10. <u>Interconnect Cable</u>. INDOT generally uses a 7C/14 signal wire when hard-wiring interconnected signals. For closed loop systems, the hard-wired connection should use a telecommunication cable consisting of either a fiberoptics cable or a 6-pair twisted cable.

77-5.06 Phasing

The traffic signal designer, in consultation with the District Traffic Section, is responsible for determining the initial phasing plan. The selected phase diagram must be included in the plans on the signal detail sheet and should include the roadway preferentially.

77-5.06(01) Phasing Types

A signal phase is defined as the part of the traffic signal cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals. Each cycle can have 2 or more phases. For practicality, it is recommended that there be no more than 8 phases per cycle and desirably fewer. As the number of non-overlapping phases increases, the total vehicular delay at the intersection will increase due to the lost time of starting and clearing each phase. The designer should strive to use the minimum number of phases practical that will accommodate the existing and anticipated traffic demands. A capacity analysis should be conducted to determine if the proposed phasing is appropriate. The designer should note that INDOT's practice is to use phase 2 and phase 6 as the preferential phases. The following presents the typical applications for various phase operations.

1. <u>Two-Phase Operation</u>. A 2-phase operation is appropriate with a 4-way intersection that has moderate turning movements and low-pedestrian volumes. Figure 77-5K illustrates a typical 2-phase operation. A 2-phase operation is also appropriate for the intersection of two 1-way streets. Some of the disadvantages of a 2-phase operation is that left turns are in conflict with traffic from opposite directions and that right- and left-turning traffic are in conflict with pedestrian flows.

2. <u>Three-Phase Operation</u>. The following describes several options where a 3-phase operation may be used as follows:

   a. Major Street with Separate Phases. A 3-phase operation with separate phases on a major street (split phase) may be used where there is heavy left-turning demand on the major street from one or both directions and there is inadequate pavement width to provide a left-turn lane (see Figure 77-5L, Three-Phase Operation (Separate Split Phases for Major Street)). This phase selection is not an efficient operation for multi-lane streets because it typically reduces capacity and increases delay.

   b. Major Street With Left-Turn Lanes. A 3-phase operation should be considered where separate left-turn lanes are provided on the major street (see Figure 77-5M). A left-turn lane will typically reduce the number of left-turn accidents. Left-turning traffic from both directions should be nearly equal.

   c. Exclusive Pedestrian Phase. This option is primarily used where there are significant number of pedestrians (e.g., universities, downtown business districts) and where the signal would normally operate in a 2-phase operation (i.e., minimum number of left-turns). Figure 77-5N illustrates a 3-phase operation with an exclusive pedestrian phase. During the exclusive pedestrian phase, pedestrians can use all crosswalks and/or walk diagonally across the intersection.

   d. T-Intersection. A 3-phase operation will typically be required if there are heavy turning volumes on the through street. The 3-phase operation allows a number of options depending on the traffic volumes and geometrics of the intersection (e.g., left- and right-turn lanes). Figure 77-5 O, T Intersections, illustrates two options.

3. <u>Four-Phase Operation</u>. A 4-phase operation may be used where left-turn lanes are provided on all four approaches and the left-turn volumes for each set of opposing turns is approximately equal. However, an 8-phase controller is generally more efficient for this type of operation. This phase operation may be used at the intersection of multi-lane major routes. It is most appropriate for actuated control with detection on all approaches.

4. <u>Eight-Phase Operation</u>. An 8-phase operation provides the maximum efficiency and minimum conflicts for high-volume intersections with heavy turning movements. Left-turn lanes should be provided on all approaches. It is most appropriate for actuated control with detection on all approaches. The 8-phase operation allows for the skipping of phases or selection of alternate phases depending upon traffic demand. Figure 77-5P illustrates a typical 8-phase operation (dual ring). An 8-phase operation uses the NEMA dual-ring controller.

5. Other Phases. For other phase operations (e.g., 6-phase operations), one of the above phase operations can be used by eliminating the nonapplicable phase from the sequence.

Figures 77-5K, 77-5L, 77-5M, 77-5N, 77-5 O and 77-5P also illustrate the movements that typically should be assigned to the various numbered phases. As a general rule, on 4- and 8-phase operations, the through phases are assigned to the even-numbered phase diagram locations, and the left turns are assigned to the odd-numbered phase diagram locations.

The controller accommodates control of each individual phase. Each phase is programmed as single-entry operation in which a single phase can be selected and timed alone if there is no demand for service in a non-conflicting phase. Where 2-through 4-phase controllers are involved (single-ring controllers), there are no concurrent phases timed. For controllers with 5 to 8 phases, normally there are phases that can be timed concurrently (dual-ring controllers). For example, a through movement can be timed concurrently with its accompanying left turn or its opposing through movement (i.e., Phase 1 can be timed concurrently with Phase 5 or Phase 6), but not with any other phase or vice versa. This concurrent timing is not an overlap because each phase times individually. An overlap is dependent on the phase or phases with which it is overlapped for time and is terminated as the phase or phases terminate.

There are several computer programs available that can assist the designer to determine the appropriate phasing requirements (see Section 77-5.09). The Design Division’s Specialty Project Group may be contacted for more information on the latest software packages or versions used by INDOT.

77-5.06(02) Left-Turn Phases

The most commonly added phases are for protected left-turns (i.e., left-turning vehicles are given a green arrow without any conflicting movements). Left-turn phases can be either a leading left, where the protected left turn precedes the opposing through movements, or a lagging left, where the left-turn phase follows the opposing through movements. The decision on when to use either a leading-left or a lagging-left turn will be determined on a case-by-case basis. In most situations, INDOT’s preferred practice is to use the leading left. Figure 77-5Q provides a comparison for each left-turn phase alternative.

Not all signalized intersections will require a separate left-turn phase. The decision on when to provide exclusive left-turn phases is dependent upon traffic volumes, delays and accident history, and this will be determined on a site-by-site basis. For intersections with exclusive left-turn lanes, the following are several guidelines that a designer may use to determine the need for a left-turn phase.

1. Capacity. A left-turn phase should be considered where the demand for left turns exceeds the left-turn capacity of the approach lane. The left-turn capacity of an approach lane is 1,200 vehicles times the percent of green time minus the opposing volume (1,200)(G/C)-*opposing volume*), but not less than two vehicles per cycle.

2. Delay. A left-turn phase should be considered where the delay time for left-turning vehicles is excessive for four hours during an average day. Delay is considered excessive when left-turning vehicles are delayed for more than two complete signal cycles.

3. Miscellaneous. In addition to capacity and delay guidelines, the designer should consider intersection geometrics, total volume demand, accident history, posted speeds, etc.

4. Non-INDOT Facilities. The ITE *Manual of Traffic Signal Design* presents alternative guidelines for when left-turn phasing may be considered.

On approaches without an exclusive left-turn lane, the decision on whether to include a left-turn phase is determined on a site-by-site basis. Where practical, opposing left-turn arrows should also be provided.

77-5.07 Pretimed Traffic Signal Timing

77-5.07(01) Guidelines for Signal Timing

For State highways, the District Traffic Section will normally be responsible for timing the signal after it has been installed. This is true for both in-house and consultant-designed projects. For local facilities, the consultant will generally be responsible for determining the signal timing. However, the traffic signal designer still must understand the aspects of traffic signal timing so that the appropriate equipment selected will provide an efficient design.

The following presents several guidelines that the designer should consider when developing the signal timing for pretimed signals.

1. Phases. The number of phases should be kept to a minimum. Each additional phase reduces the effective green time available for the movement of traffic flows (i.e., increased lost time due to starting delays and clearance intervals). Adding concurrent phases may not reduce capacity.

2. Cycle Lengths. Short cycle lengths yield the best performance by providing the lowest average delay, provided the capacity of the cycle to pass vehicles is not exceeded. In general, the designer should consider the following relative to cycle lengths.

   a. Delay. For 2-phase operation, shorter cycle lengths of 50 to 60 s generally produce the shortest delays.

   b. Capacity. Longer cycle lengths (greater than 60 s) will accommodate more vehicles per hour if there is a constant demand during the entire green period on each approach. Longer cycle lengths have higher capacity because, over a given time period, there are fewer starting delays and clearance intervals.

   c. Maximum. Normally, a cycle length of 120 s should be the maximum used, irrespective of the number of phases. For more than a 120-s cycle, there is an insignificant increase in capacity and a rapid increase in the total delay.

3. Green Intervals. The division of the cycle into green intervals will be approximately correct if made proportional to the critical lane volumes for the signal phases. The critical lane volumes can be quickly determined by using the Planning Methodology from the *Highway Capacity Manual*. In addition, the designer should check the green interval against the following:

   a. Pedestrians. If pedestrians will be accommodated, each green interval must be checked to ensure that it is not less than the minimum green time required for pedestrians to cross the respective intersection approaches plus the initial walk interval time.

   b. Minimum Lengths. In general, relative to driver expectations, major movements should not have green intervals which are less than 15 s. An exception to this may be appropriate for special turn phases.

4. Capacity. For intersection approaches with heavy left turns, the capacity of an intersection should be checked to determine the need for a separate left-turn lane; see Section 77-5.06(02).

5. Phase Change Interval. Each phase change interval (yellow plus all red) needs to be checked to ensure that approaching vehicles can either come to a stop or clear the intersection during the change interval.

6. Coordination. Traffic signals within 800 m of each other should be coordinated together in a system. Section 77-6.0 further discusses signal system coordination.

7. Field Adjustments. All signal timing programs should be checked and adjusted in the field to meet the existing traffic conditions.

77-5.07(02) Cycle Determinations

In determining the appropriate cycle length and interval lengths, the designer should consider the following:

1. General. Cycle lengths should generally fall within the following ranges.

    a. 2-Phase Operations: 50 - 80 s.
    b. 3-Phase Operations: 60 - 100 s.
    c. 4-Phase Operations: 80 - 120 s.

2. Phase Change Interval. The yellow change interval advises drivers that their phase has expired and that they should stop prior to the stop line, or allows them to enter the intersection if they are too close to stop. The phase change interval length can be determined using Equation 77-5.1. The yellow change interval may be followed by a red-clearance interval (all-red phase) of sufficient duration to permit traffic to clear the intersection before conflicting traffic movements are released. For more efficient operations, start-up time for the conflicting movements may be considered when setting the length of the all-red.

$$Y + AR = t + \frac{V}{2a \pm 19.6g} + \frac{W + L}{V} \qquad \text{(Equation 77-5.1)}$$

Where:

$Y + AR$ = Sum of the yellow and any all-red, s

t = perception/reaction time of driver, s (typically assumed to be 1 s)

V = approach speed, m/s

a = deceleration rate, m/s^2 (typically assumed to be 3.0 m/s^2)

W = width of intersection, m

L = length of vehicle, m (typically assumed to be 6.0 m)

g = approach grade, percent of grade divided by 100 (add for upgrade and subtract for downgrade)

Yellow change intervals typically are in the range of 3 to 6 s. The typical maximum all-red interval used by INDOT is 2 s.

3. Green Interval. To determine the cycle division, the phase green interval should be estimated using the proportion of the critical lane volumes for each phase. The following equations illustrate how to calculate this proportion for a 2-phase system. Signals with additional phases can be determined in a similar manner.

$$G = C - Y_a - Y_b \qquad \text{(Equation 77-5.2)}$$

$$G_a = G\left(\frac{V_a}{V_a + V_b}\right) \qquad \text{(Equation 77-5.3)}$$

$$G_b = G\left(\frac{V_b}{V_a + V_b}\right) \qquad \text{(Equation 77-5.4)}$$

Where:

G = total green time available for all phases, s

G_a & G_b = green interval in seconds calculated for streets A and B

V_a & V_b = critical lane volumes on streets A and B

Y_a & Y_b = phase change interval in seconds on streets A and B (Yellow and All Red)

C = cycle length, s

The designer also should consider the effect the pedestrian clearance interval will have on the green interval where there is an exclusive pedestrian phase, or if the pedestrian phase runs concurrently with traffic at wide intersections with short green intervals. If pedestrians walk on the green indication or on a Walk indication, the minimum green

$$G = P + \frac{D}{S} - Y \qquad \text{(Equation 77-5.5)}$$

interval should be determined using Equation 77-5.5. The walking distance is from the edge of the near roadway to the center of the farthest travel lane.

Where:

G = minimum green time, s
P = pedestrian start-off period, normally 4-7 seconds
D = walking distance, m
Y = yellow interval, s
S = walking speed, m/s (normally 1.2 m/s)

Where there are fewer than 10 pedestrians per cycle, the lower limit of 4 s is normally adequate as a pedestrian start-off period. A walking speed of 1.2 m/s can be assumed for average adult pedestrians. Where significant volumes of elderly, handicapped or child pedestrians are present, then a reduced walking speed should be considered.

4. Recheck. After the cycle length and interval lengths have been selected, the designer should recheck the design to ensure that sufficient capacity is available. Also, the designer may want to check several cycle lengths to ensure that the most efficient cycle length and interval lengths are used. If the initial design is inadequate, the designer will need to perform the following:

   a. select different cycle length;

   b. select a different phasing scheme; and/or

   c. make geometric or operational changes to the intersection approaches (e.g., add left-turn lanes).

   There are several software programs available to assist in determining the most efficient design. Section 77-5.09 discusses several of these programs.

77-5.08 Actuated Controller Settings

As with pretimed controllers, the district traffic engineer will normally be responsible for timing actuated controllers on State highways after they are installed. However, the traffic signal designer must understand how the signal timing will affect the efficiency of the actuated signalized intersection. In addition, with actuated controllers, the traffic signal designer must understand how the signal timing will affect the placement of the traffic detectors.

The design of actuated control is basically a trade-off process where the designer attempts to optimize the location of vehicular detection to provide safe operation, but yet provide controller settings that will minimize the intersection delay. The compromises that must be made among these conflicting criteria become increasingly difficult to resolve as approach speeds increase.

For example, on high-speed approaches (i.e., greater than 50 km/h), the detector should be located in advance of the dilemma zone. The dilemma zone is the decision area, on high-speed approaches, where the driver needs to decide whether to go through the intersection or stop when the yellow interval begins. Depending on the distance from the intersection and vehicular speed, the driver may be uncertain whether to stop or continue through the intersection, thus, creating the dilemma problem. Figure 77-5R further defines the dilemma zone. The following sections discuss some of the design considerations for actuated controllers.

77-5.08(01) Basic-Actuated Controllers

Basic-actuated control with passage detection is limited in application to isolated intersections with fluctuating or unpredictable traffic demands and approach speeds of 50 km/h or less. Basic-actuated control includes full-actuated and semi-actuated control equipment. INDOT generally does not use this type of signal control (see Section 77-5.08(02)).

Because of the small area covered by the small loop detector and its location from the stop bar, this type of detection is only typically used with controllers that have a locking memory feature for detector calls (i.e., the controller remembers the actuation of a detector on the yellow or red, or the arrival of a vehicle that did not receive enough green time to reach the intersection).

In developing the timing criteria and the detector placement for basic-actuated controllers, the designer should consider the following:

1. <u>Minimum Assured Green (MAG)</u>. Although there is no timing adjustment labeled MAG on the controller, the designer still must calculate the MAG. The minimum green time is composed of the initial green interval plus one vehicle extension. Long minimum greens should be avoided. For snappy operations, normally, the minimum assured green should be between 10 and 20 s for any major movement. The actual value selected should be based on the time it takes to clear all possible stored vehicles between the stop bar and the detector. If the MAG is too short, the stored vehicles may be unable to reach the stop bar before the signal changes. This time can be calculated using Equation 77-5.6.

   $$MAG = 3.7 + 2.1\,n \qquad \text{(Equation 77-5.6)}$$

   Where:

   MAG = minimum assured green, s

   n = number of vehicles per lane which can be stored between the stop-bar and the detector

The minimum green time selected should be able to service at least two vehicles per lane. Using Equation 77-5.6, this translates into a time of approximately 8 s. Assuming two vehicles occupy approximately 14 m, the detector should not be placed closer than 14 m from the stop line. Closer placement will not reduce the MAG.

Where pedestrians must be accommodated, a pedestrian detector (e.g., push button) should be provided. Where a pedestrian call has been detected, the MAG must be sufficient enough for the pedestrian to cross the intersection. The minimum times for pedestrians, as discussed in Section 77-5.07 for pretimed signals, is also applicable to actuated systems.

2. <u>Vehicular Extension</u>. The vehicular extension setting fixes both the allowable gap and the passage of time at one value. The extension should be long enough so that a vehicle can travel from the detector to the intersection while the signal is held in green. However, the allowable gap should be kept reasonably short to assure quick transfer of green to the side street. Typical headways between vehicles in platoons average between 2 and 3 s. Therefore, the minimum vehicular extension time should be at least 3 s. For the maximum gap, studies have shown that drivers waiting on red find that gaps of 5 s or more are too long and inefficient. Therefore, the vehicular extension should be set between 3 and 5 s. Desirably, for quicker phase changes, shorter gaps should be used (e.g., 3 to 3.5 s).

3. <u>Initial Green</u>. The initial green setting is simply the MAG minus one vehicular extension. Typically, the initial green should be limited to a maximum of 10 s.

4. <u>Detector Placement</u>. The detector setback distance should be set equal to the time required for the typical vehicle to stop before entering the intersection. The vehicular passage time is typically used to determine this placement (e.g., 5.0 s). The posted speed of the approach roadway should be used to determine the appropriate setback.

5. <u>Maximum Green Interval</u>. This is the maximum time the green should be held for the green phase, given a detection from the side street. Typically, for light to moderate traffic volumes, the signal should “gap out” before reaching the maximum green time. However, for periods with heavy traffic volumes, the signal may rarely gap out. Therefore, a maximum green interval is set to accommodate the waiting vehicles. The maximum green interval can be determined assuming a pretimed intersection (see Section 77-5.07). It may be somewhat longer to allow for peaking.

6. <u>Clearance Interval</u>. The clearance interval should be determined in the same manner as for pretimed signals (see Section 77-5.07).

7. Left-Turn Lanes. Left-turn lanes should be treated like side streets with semi-actuated control. Short allowable gaps and minimum greens should be used. The designer must be careful of vehicles which may enter the left-turn lane beyond the detector. If this may be a problem, a presence detector should be considered at the stop bar (see Section 77-5.08(03)).

8. Semi-Actuated Controllers. For minor streets with semi-actuated control, the signal is normally held on green for the major street. To ensure that the mainline is not interrupted too frequently, large minimum greens should be used on the major street. It is normally expected that the low-volume minor street will experience delay.

9. Intermediate Traffic. Where vehicles can enter the roadway between the detector and intersection (e.g., driveways, side parking) or where a vehicle may be traveling so slow that it does not clear the intersection in the calculated clearance time, the signal controller will not register their presence. A presence detector at the stop bar may be required to address these situations; see Section 77-5.08(03).

77-5.08(02) Advanced-Design Actuated Controllers

Advanced controllers are usually used at isolated intersections with fluctuating or unpredictable traffic demands, and approach speeds greater than 50 km/h. INDOT typically uses this type of controller, irrespective of the approach speed. An advanced-actuated controller with advanced design is one that has a variable initial interval. It can count waiting vehicles beyond the first and can extend the initial interval to meet the needs of the number of vehicles actually stored between the stop bar and the detector. As with basic-actuated control, the small area detection requires that the controller have a locking memory.

The timing for advanced-design actuated controllers requires a significant amount of judgement. Therefore, field adjustments are often required after the initial setup. The following discusses several considerations in the signal timing and detector placement:

1. Detector Placement. For high-speed approaches (i.e., greater than 50 km/h), the detector should be located in advance of the dilemma zone (see Figure 77-5R). This will typically place the detector about 5 seconds of passage time from the intersection. The speed selected should be the posted speed of the approach roadway. Figure 77-5S provides the appropriate detector set-back distances for various combinations of passage times and approach speeds. Figure 77-5S also provides the passage times that are appropriate for various other types of actuated controllers.

2. Minimum Initial. Because the advanced-actuated controller can count the number of vehicular arrivals, the minimum initial time should only be long enough to meet driver expectancy. Typically, the minimum initial interval is set at 8 to 15 s for through movements and 5 to 7 s for left turns.

3. Variable Initial. The variable initial is the upper limit to which the minimum initial can be extended. It must be long enough to clear all vehicles that have accumulated between the detector and the stop line during the red. The variable initial is determined in the same manner as the minimum assured green for the basic-actuated control; see Section 77-5.08(01).

4. Number of Actuations. The number of actuations is the number of vehicles that can be accommodated during the red that will extend the initial green to the variable initial limit. This is a function of the number of approach lanes, average vehicle length and lane distribution. It should be set based on the worst-case condition (i.e., vehicles are stored back to the detector).

5. Passage Time. The passage time is the time required for a vehicle to pass from the detector to the stop line. This is typically based on the posted speed of approach roadway.

6. Maximum Green. The maximum green should be set the same as the basic controller, see Section 77-5.08(01).

7. Allowable Gap. Density-type controllers permit a gradual reduction of the allowable gap to a preset minimum gap based on one or more cross-street traffic parameters - time waiting, cars waiting and/or density. Generally, time waiting has been found to be the most reliable and usable. As time passes after a conflicting call, the allowable gap time is gradually reduced. The appropriate minimum gap setting will depend on the number of approach lanes, the volume of traffic and the various times of day. Fine-tuned adjustments will need to be made in the field.

8. Clearance Interval. The clearance interval should be determined in the same manner as for pretimed signals (see Section 77-5.07).

77-5.08(03) Actuated Controllers with Large Detection Areas

Large area detectors are used with a basic-actuated controller in the “non-locking” memory mode and with the initial interval and vehicular extension set at or near zero. This is referred to as the loop occupancy control (LOC). Large area detectors are used in the presence mode, which holds the vehicle call for as long as the vehicle remains over the loop. One advantage of large area detectors is that they generally reduce the number of false calls due to right-turn-on-red vehicles. INDOT's large area detector consists of four octagonal 1.8-m x 1.8-m small loops, 2.7 m apart connected in series; see the INDOT *Standard Drawings*. With large area detectors, the length of the green time is determined by the time the area is occupied. However, a minimum green time of 8 to 15 s should be provided for driver expectancy. The following discusses several applications for LOC.

1. <u>Left-Turn Lanes</u>. An LOC arrangement is appropriate for left-turn lanes where left turns can be serviced on a permissive green or yellow clearance or where vehicles can enter the left-turn lane beyond the initial detector. The designer should consider the following when using the LOC for left-turns.

   a. To ensure that the driver is fully committed to making the left turn, the initial loop detector may need to be installed beyond the stop line to hold the call.

   b. Where motorcycles are a significant part of the vehicular fleet, the vehicular extension may need to be set to 1 s so that a motorcycle will be able to hold the call as it passes from loop to loop. An alternative would be to use the extended-call detector.

2. <u>Through Lanes (Low-Speed Approaches)</u>. On low-speed approaches (50 km/h or less), the dilemma zone protection is generally not considered a significant problem. The detection area length and controller settings are determined based on the desired allowable gap. For example, assuming a 50 km/h approach speed and 3-s desired allowable gap, the LOC area is calculated to be as follows:

$$\frac{50\ km}{h} \ x\ 3\ s\ x \frac{1000\ m}{km} \ x \frac{h}{3600\ s} = 42\ m$$

   The vehicular length (6 m) should be subtracted from the LOC, so the required detector area is 36 m. INDOT's typical loop layout is only 14-m long; therefore, for a 50-km/h approach speed, the vehicular extension setting should be set at 1.5 s to provide the 3-s gap.

   If the initial interval is set at zero and the vehicular extension is between zero and 1 second then, under light traffic conditions, a green as short as 2 or 4 s may occur. The designer should check to determine if there are pedestrian or bicyclists present; if so, the minimum green times for their crossings should be provided. Driver expectancy should also be considered. Generally, drivers for major through movements expect a minimum green interval of 8 to 15 s.

3. <u>Through Lanes (High-Speed Approaches)</u>. For high-speed approaches (speeds greater than 50 km/h), it is generally not practical to extend the LOC beyond the dilemma zone (5 s of passage time back from the stop bar). To cover the dilemma zone problem, an extended-call detector is placed beyond the dilemma zone. This detector is used in a non-locking mode. The time extension is based on the time for the vehicle to reach the LOC area. Intermediate detectors may be used to better discriminate the gaps.

   There are several concerns with using the LOC concept for high-speed approaches. Some of these concerns include the following:

   a. The allowable gap is generally higher than the normally desired 1.5 to 3 s. The controller’s ability to detect gaps in traffic is substantially impaired. As a result, moderate traffic will routinely extend the green to the maximum setting - an undesirable condition.

   b. For high-speed approaches, LOC designs should only be used if the route is lightly traveled (e.g., 8,000 to 10,000 ADT). High-speed approaches with heavy volumes are better served with density controllers. The intersection of a high-speed artery with a low-speed crossroad might be better served by using a density controller on the artery and LOC for the crossroad.

<u>77-5.09 Computer Software</u>

There are numerous software programs available to help assist the designer in preparing traffic signal designs and timing plans. New programs, as well as updates to existing programs, are continuously being developed. Before using these programs, the designer should contact the Traffic Design Section to determine which software packages or versions INDOT is currently using. The following programs are the most widely used for signal timing optimization.

1. <u>SOAP</u>. The Signal Operations Analysis Package (SOAP) program develops fixed-time, signal-timing plans for individual intersections. SOAP can develop timing plans for six design periods in a single run. It can also analyze 15-min volume data for up to 48 continuous time periods and determine which timing plan is best suited for each 15-min period. A data input manager is included with the program to facilitate data entry.

2. <u>PASSER II and MAXBAND</u>. Progression Analysis and Signal System Evaluation Routine (PASSER II) and MAXBAND are known as bandwidth-optimization programs. They develop timing plans that maximize the through progression band along arterials of up to 20 intersections. Both programs work best in unsaturated traffic conditions and where turning movements onto the arterial are relatively light. PASSER II and

MAXBAND can also be used to develop arterial phase sequencing for input into a stop-and-delay optimization model such as TRANSYT-7F.

3. TRANSYT-7F and SIGOP-III. The Traffic Signal Network Study Tool (TRANSYT-7F) and the Signal Timing Organization Program (SIGOP-III) develop signal-timing plans for arterials or grid networks. The objective of both programs is to minimize stops and delays for the system as a whole, rather than maximizing arterial bandwidth.

4. Arterial Analysis Package. The Arterial Analysis Package (AAP) allows the user to easily access PASSER II and TRANSYT-7F to perform a complete analysis and design of arterial signal timing. The package contains a user-friendly forms display program so that data can be entered interactively on a microcomputer. Through the AAP, the user can generate an input file for any of the two component programs to quickly evaluate various arterial signal-timing designs and strategies. The package also links to the "Wizard of the Helpful Intersection Control Hints" (WHICH) to facilitate detailed design and analysis of the individual intersections. The current program interfaces with TRANSYT-7F, PASSER II and WHICH.

5. Highway Capacity Software. The Highway Capacity Software (HCS) replicates the procedures described in the *Highway Capacity Manual*. It is a tool that greatly increases productivity and accuracy, but it should only be used in conjunction with the *Highway Capacity Manual* and not as a replacement for it.

6. TRAF-NETSIM. TRAF-NETSIM is a microscopic program that can be used to simulate traffic operations for arterials, isolated intersections and/or roadway networks. It can be used to determine delay, queue length, queue time, stops, stop times, travel time, speeds, congestion measures, etc. However, it does not have optimizing capabilities (i.e., the user must conduct multiple simulations to determine the "best" signal timing). It can be used with both fixed-timed and/or actuated-controlled intersections.

7. COPTRAFLO. COPTRAFLO can be used to develop time-based diagrams for arterials. It can be used to determine the optimal traffic band for both one-way or two-way arterials. The program will also allow the user to review all available solutions and will provide the offsets for the system signals based on speed and cycle lengths.

Most of these software programs can be purchased from either McTrans Center, 512 Weil Hall, Gainesville, Florida 32611-2083; or from PC-TRANS, Kansas University Transportation Center, 2011 Learned Hall, Lawrence, Kansas 66045. Many of these software programs can be purchased for either the mainframe or PC-based computer.

77-5.10 Maintenance Considerations

After a signal is installed, the district traffic section will be responsible for the maintenance of the traffic signal. Therefore, they should be consulted early in the design process for the selected signal equipment (e.g., controllers, cabinets, load switches, signal heads, lamps, etc.). The selected equipment must meet the operator's capability to adjust the signal and maintain it.

For signals on local facilities, it will be the responsibility of the local municipality or county to operate and maintain the signal. The designer should review the local jurisdiction's existing traffic signal hardware and maintenance capabilities. Wherever practical, the designer should attempt to match the local jurisdiction's existing hardware. This will reduce the municipality's need for additional resources and personnel training. However, this should not necessarily limit the designer's options, because there are several consultants who can help local governments operate and maintain any traffic signal.

77-6.0 SIGNAL SYSTEM DESIGN

As traffic volumes continue to grow, installation of coordinated signal systems is an important tool to improve traffic flow. By coordinating two or more traffic signals together, the overall capacity of the highway can be significantly increased. Generally, traffic signals 800 m or less apart should be considered for coordination. Although not a perfect solution, the use of a coordinated traffic signal system could satisfy the traffic needs of the highway for several years. It is also a relatively inexpensive method of improving capacity, thereby reducing delay, with minimal disruption to the highway as compared to the construction of additional lanes.

77-6.01 System-Timing Parameters

The basic system-timing parameters used in a coordinated system include the following:

1. Cycle. The period of time in which a pretimed controller (or an actuated controller, with demand on all phases) displays a complete sequence of signal indications. In most systems, the cycle length is common to all intersections operating together and is called the background cycle.

2. Split. The proportioning of the cycle length among the various phases of the local controller.

3. Offset. The time relationship determined by the difference between a specific point in the local signal sequence (typically the beginning of the major street green interval) and a system-wide reference point.

4. Time of Day / Day of Week. The time-of-day/day-of-week system selects system timing plans based on a predefined schedule. The timing plan selection may be based not only on the time of day but also on the day of week and week of year. Some systems permit the selection of plans based upon a specific day of the year.

5. Traffic Responsive. Traffic responsive systems implement timing patterns based on varying traffic conditions in the street. Most traffic-responsive systems select from a number of predefined patterns. These systems use a computerized library of predefined timing patterns that are based on data collected by the system to develop the timing plan for the system.

77-6.02 System Types

There are several different methodologies available to coordinate traffic signals. Most of these take advantage of computer technology. As new signal controllers, computers and software are developed, the design of coordinated traffic signal systems will continue to improve. These systems should match existing systems and/or be coordinated with nearby systems. In general, traffic signal systems are designed by consultants who specialize in traffic signal systems. To maintain consistency, all traffic signal system designs must be coordinated through the Traffic Design Section. The following sections briefly describe several of these systems.

77-6.02(01) Interconnected Time-of-Day System

The interconnected time-of-day system is applicable to both pretimed and actuated controllers, in either a grid system or along an arterial system. The typical configuration for this type of system includes a field-located, time clock-based master controller generating pattern selection and synchronization commands for transmission along an interconnecting cable. Local intersection coordination equipment interprets these commands and implements the desired timing.

77-6.02(02) Time-Base-Coordinated Time-of-Day System

Operationally equivalent to the interconnected time-of-day system, this type of system uses accurate timekeeping techniques to maintain a common time of day at each intersection without physical interconnection. Time-base coordination is tied to the 60 Hz AC power supply, with a battery backup in case of a power failure.

Time-base coordination allows for the inexpensive implementation of a system, because the need for an interconnect cable is eliminated. However, time-base systems require periodic checking by maintenance personnel, because the 60 Hz power company reference is sometimes inconsistent. In addition, power outages sometimes affect only portions of a system, resulting in drift between intersections that continue to operate on power company lines and those that maintain time on a battery backup.

Time-base coordination often is used as a backup for computerized signal systems.

77-6.02(03) Traffic-Responsive Arterial Systems

The traffic-responsive arterial system concept is normally used with semi-actuated controllers along an arterial. The field located system master selects predetermined cycle lengths, splits and offsets based upon current traffic flow measurements. These selections are transmitted along an interconnect cable to coordination equipment at the local intersections.

Cycle lengths typically are selected based on volume (and sometimes occupancy) level thresholds on the arterial; the higher the volumes, the longer the cycle length. Splits frequently are selected based on the side-street volume demands, and offsets are selected by determining the predominant direction of flow along the arterial.

System sampling detectors, located along the arterial, input data back to the master controller along the interconnect cable. Most current systems have the capability to implement plans on a time-of-day basis as well as through traffic-responsive techniques.

77-6.02(04) Distributed-Master (Closed-Loop) Systems

The distributed-master (frequently called closed-loop) system advances the traffic-responsive arterial system one step further by adding a communications link between the field-located master controller and an office-based microcomputer. Most systems are designed to interface with a standard personal computer over dial-up telephone lines. This connection is established only when the field master is generating a report or when the operator is interrogating or monitoring the system. With proper equipment, several systems can share a single office-based microcomputer.

The system permits the maintenance of the complete controller database from the office. The controller's configuration data, phase and timing parameters, and coordination patterns can be downloaded directly from the office.

The distributed-master system provides substantial remote monitoring and timing plan updating capabilities for only a minor increase in cost - typically, only the expense of the personal computer and the monthly costs of a standard business telephone line. Graphics displays are usually provided to assist in monitoring the system.

77-6.02(05) Central Computer Systems (Interval-Command Systems)

This system can control large numbers of intersections from a central digital computer. This system requires constant communications between the central computer and each local intersection. The central computer determines the desired timing pattern parameters, based either on time-of-day or traffic-responsive criteria, and issues commands specific to each intersection once per second. These commands manipulate the controller into coordinated operation.

The system also monitors each intersection once per second. Detector data, current phase green, and other information is transmitted back to the computer for necessary processing. Many systems include a large-wall-size map display, with indicators showing controller and detector status and other informational displays. Some systems include a color graphics monitoring system.

Typically, systems of this type require a large minicomputer, complete with a conditioned, environmentally controlled computer room.

77-6.02(06) Central Database-Driven Control Systems

This system draws from the good points of both the distributed-master system and the central-computer system. Although communications are maintained continuously with each intersection, timing pattern parameters are downloaded to each controller, eliminating most of the second-by-second approach. This allows a greater number of intersections to be controlled by a less powerful computer.

The reduction in communications data required also allows an increase in monitoring data being returned to the computer. Thus, the complex graphics displays normally found in distributed-master systems can also be implemented in a large-scale system.

77-6.03 Communications Techniques

Systems other than time-base-coordinated systems require some type of communications medium to maintain synchronized operation between intersections. Two primary options are available for system interconnection - hardwired communications and through-the-air frequency. Hardwired communications may include leased telephone lines, cable television lines, fiber optics or direct wired. Through-the-air interconnections may include radio, microwave or cellular telephones. The requirements for the communications network are dependent on the needs of the system. Therefore, the decision on which interconnection to use will be determined on case-by-case basis.